

# West Texas Mesonet Observations and Four-Dimensional Data Assimilation for Testing MM5 and HPAC

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## **ABSTRACT:**

In this paper we investigate mesoscale model predicted boundary-layer winds and the subsequent HPAC (Hazard Prediction and Assessment Capability) dispersion computation. The HPAC software allows for prediction of the effects of surface release of chemical/biological agents into the atmosphere and collateral damage on civilian populations using either observed or weather model winds. The mesoscale model MM5 was tested in the study. The model simulations were run using real terrain and verified with the field data in western Texas. High-resolution West Texas Mesonet observations were collected and used to provide data for the MM5 four-dimensional- data-assimilation (FDDA) experiments. The Mesonet is a grid of about 35 automated surface weather stations spaced about 40 km apart, providing a high spatial and temporal resolution surface meteorological dataset for testing boundary layer processes and mesoscale models. FDDA input files of hourly or 30-minute wind, temperature, and humidity observations for the selected cases were created using a data array of 5-minute observations. MM5 worked well in simulating meteorologically relatively quiescent conditions. The simulation experiments suggest that the sensitivity of HPAC diffusion model computation may be a strong function of the environmental conditions. A composite approach of averaging HPAC runs with different model winds may result in a more accurate prediction of boundary-layer transport of chemical/biological agents.

## **1. Introduction**

The release of chemical/biological (CB) agents or other toxic materials, whether from an accidental or deliberate act, represents a real threat to large populations. The development of a real-time operational prediction and warning system is essential for effective evacuation and damage mitigation during such events. A central issue is to understand how CB agents are physically transported in the atmospheric boundary layer (BL), in particular, the lower BL near the surface. Mesoscale meteorological processes on a scale of a few to 100 km resulting from surface heating, terrain forcing, and turbulent mixing would be expected to play a critical role in the spread of CB agents near the surface. In this study, we are probing whether a set of existing state-of-the-art numerical weather prediction (NWP) and observation techniques in conjunction with applicable diffusion models are capable of accurately depicting the surface CB transport and providing useful guidance in case of a CB attack.

The mesoscale numerical weather prediction system MM5 (Grell *et al.*, 1994) and diffusion model HPAC (Hazard Prediction and Assessment Capability) are selected in this study. The focus is on the MM5 simulated surface flow and the subsequent HPAC diffusion computations. MM5 is evaluated in simulating various meteorological settings including relatively quiescent

conditions and convective activity in West Texas (Gill *et al.* 2003). The HPAC software allows for prediction of the effects of surface release of hazardous material into the atmosphere and collateral damage on civilian populations using either observed or model meteorological data (HPAC User's Guide, 2001). A real-data MM5-HPAC simulation of a case study is also presented. MM5 model results are verified with the high-resolution data sets obtained from the West Texas Mesonet. We use the HPAC prediction based on the Mesonet data as a benchmark for qualitative assessment of the MM5-HPAC simulations. This allows us to address two important scientific questions: the impact of

- (a) the NWP model's grid resolution and lateral boundary conditions (BC) and
- (b) weather data

on surface hazardous agent forecasting. Answers to these questions should facilitate the development of a reliable and operational CB warning system.

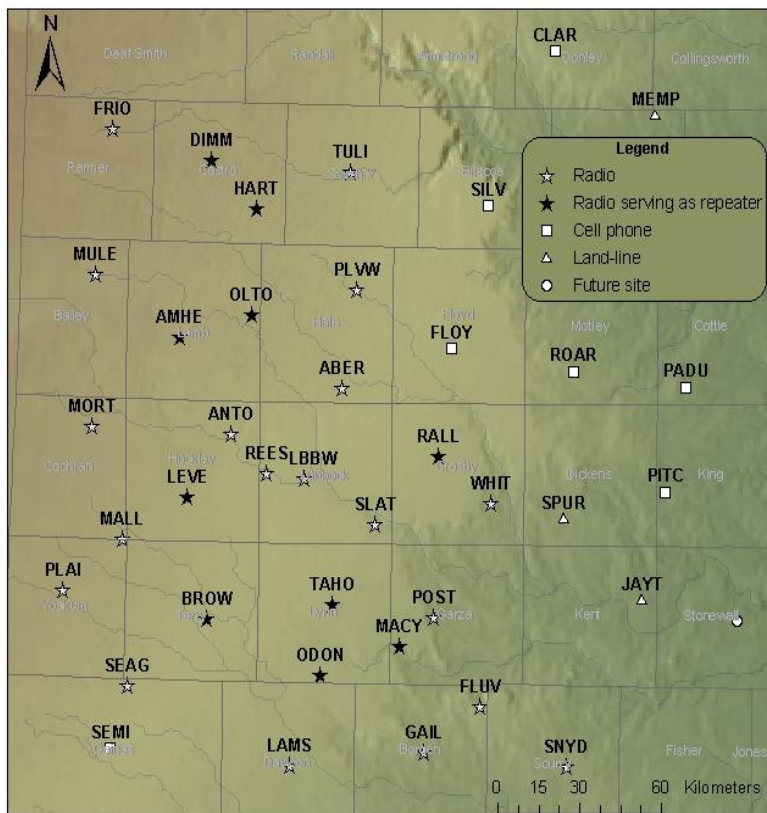
## **2. The West Texas Mesonet**

At Texas Tech University in Lubbock, Texas, atmospheric scientists and wind engineers are developing and assembling an array of advanced fast-response high-resolution atmospheric monitoring systems to study surface airflow and dispersion processes in the horizontal and vertical directions. The central component of the array is the West Texas Mesonet (WTM). The WTM includes both fixed and mobile observation platforms. The WTM's automated surface network provides continuous coverage of a region centered at Lubbock (Figures 1 and 2) and consists of approximately 40 fixed 10-m instrumented towers (Figure 3), several boundary layer towers of height ranging from 70 to 200 m, and other mobile platforms. The average spacing of the fixed towers is about 40 km. The site locations were selected depending on both geographic availability/appropriateness and considerations made for communications purposes. Three of these sites have atmospheric profilers (Figure 4) capable of sampling wind and stability measurements of the lowest several kilometers of the atmosphere. The tower observations include five-minute data on temperature, humidity, barometric pressure, wind speed (3-second observations), wind direction, precipitation, and solar radiation. In addition, data on soil moisture and soil temperature are collected every 15 minutes. More complete Mesonet tower specifications and locations are available at <http://www.mesonet.ttu.edu>. The West Texas Mesonet provides a unique opportunity for research in many aspects of atmospheric BL and surface processes.

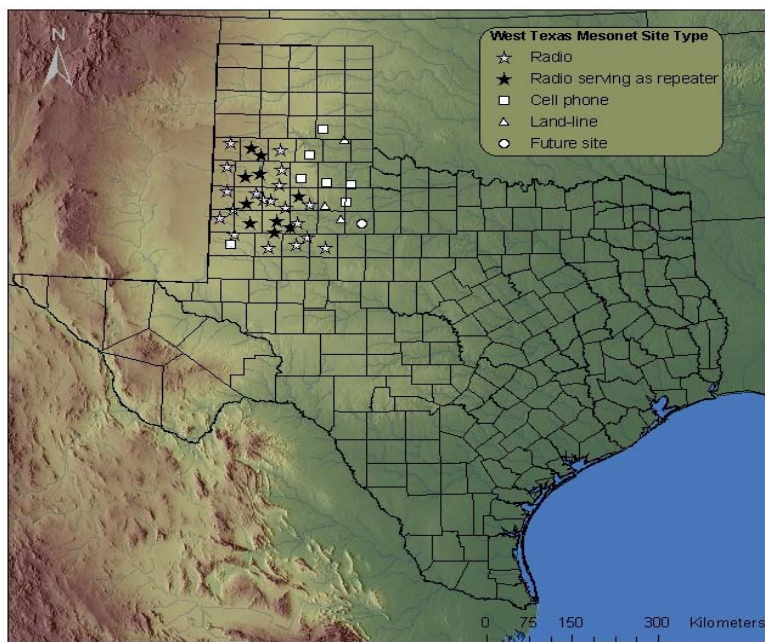
In 2002 quality control procedures were developed for application to the Mesonet data sets (Gill *et al.*, 2003). These procedures consisted of a suite of tests including:

- (1) checking the expected normal ranges of the data,
- (2) checking that the data is within the range limitations of the instrumentation,
- (3) checking the temporal continuity of the data,
- (4) checking the spatial continuity of the data, and
- (5) checking the collected data against other like instruments on the same platform.

In the current study, only the quality controlled fixed 10-m tower observations were considered. The 5-min average of the tower data were used to create hourly winds and temperatures for HPAC diffusion computations and MM5 post-forecast verification. Case studies are taken from the year 2002 WTM dataset.



**Figure 1. Locations of West Texas Mesonet sites as of summer 2003.**



**Figure 2. Location of the West Texas Mesonet within the state of Texas.**



**Figure 3. A typical West Texas Mesonet station.**



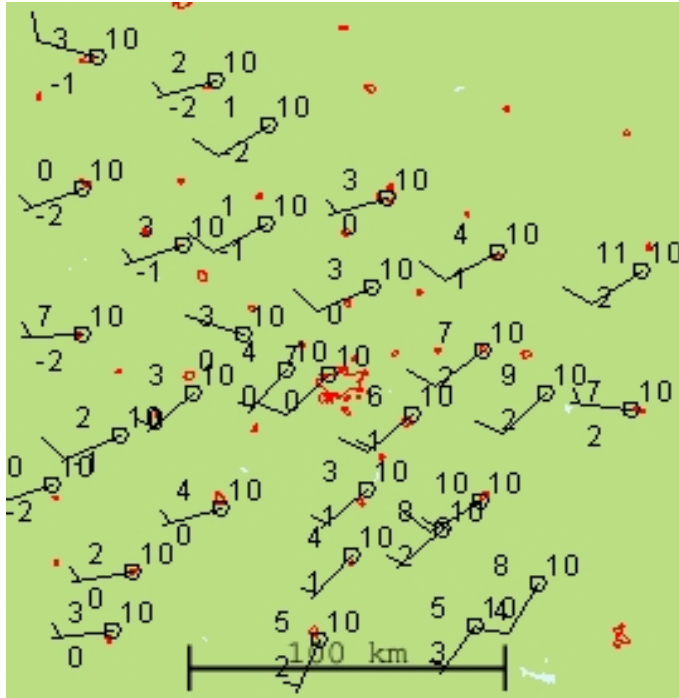
**Figure 4. Profiler at West Texas Mesonet Reese Center (REES) site.**

The Mesonet surface data can be used to initialize mesoscale models, to provide high-frequency observations for data assimilation, or to validate model simulations. The desired result is to have an improved understanding of how mesoscale numerical model and high resolution surface data sets can be used in regional numerical weather forecasting. In this work, we focus on MM5-predicted surface conditions. 10-m Mesonet tower data was used for several case studies selected from the 2002 data archive. The data utilized were the 5-minute surface winds (averages of the 3-second values) at 10 meters, and 5-minute temperature and relative humidity measured at 1.5 meters.

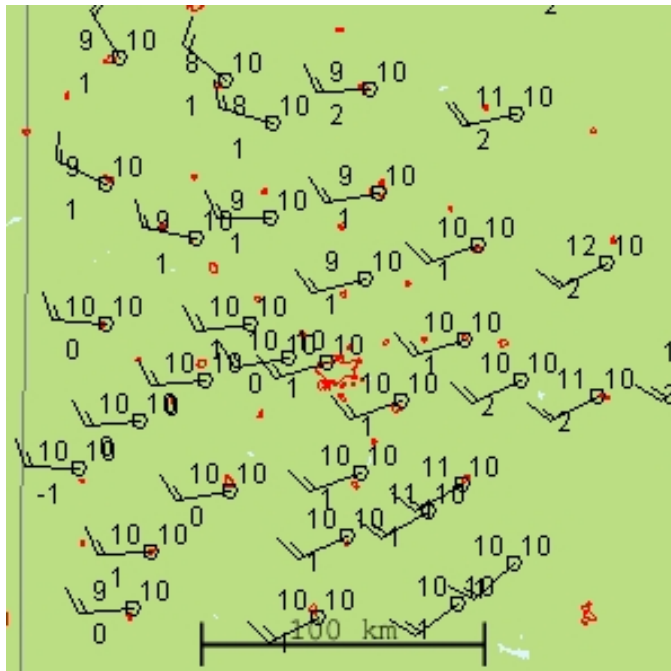
- The model initial states and boundary conditions were generated from the NCEP ETA model analyses.

- This represents a case of tranquil autumn conditions with no precipitation over West Texas. MM5 was run in single grid (mesh size  $\Delta = 18$  km) simulations starting at 00 UTC, 23 November. Case S1 (Figure 5) represents the 12-hour MM5 surface simulation. Figures 6a and 6b below represent the 12-hour observations at the West Texas Mesonet sites and the 12-hour MM5 simulated conditions for those points.





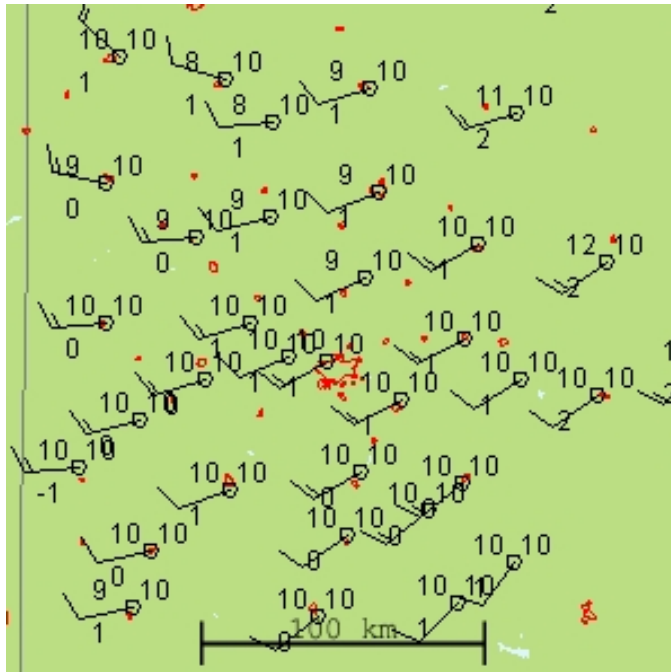
**Figure 6a. 12-hour observations at the West Texas Mesonet sites for S1.**



**Figure 6b. 12-hour MM5 simulated observations at the West Texas Mesonet sites for S1.**

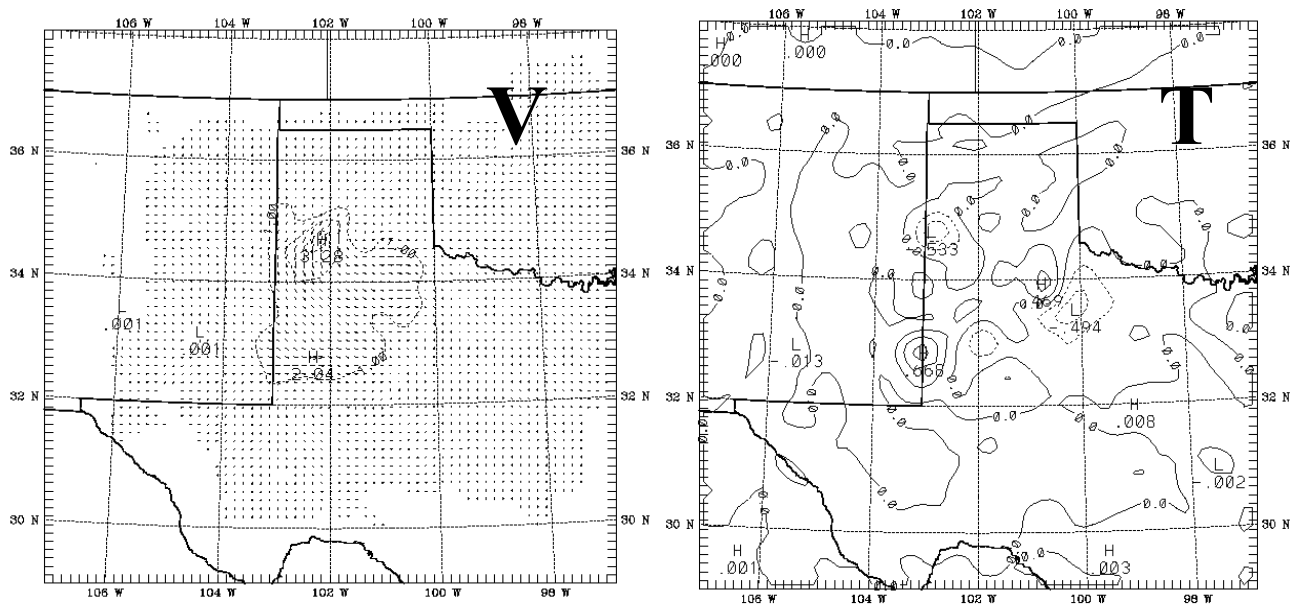
Two FDDA runs (Cases S2) were also performed for this case. In case S2A, observational nudging was performed every hour from 6h to 12h. In case S2B, nudging was performed from 3h to 12h. At 12h, only very minor differences were noted between S2A and S2B. Case S2A observations are shown below in Figure 7.





**Figure 7. 12-h MM5 FDDA simulation with observational nudging performed every hour from 6h to 12h.**

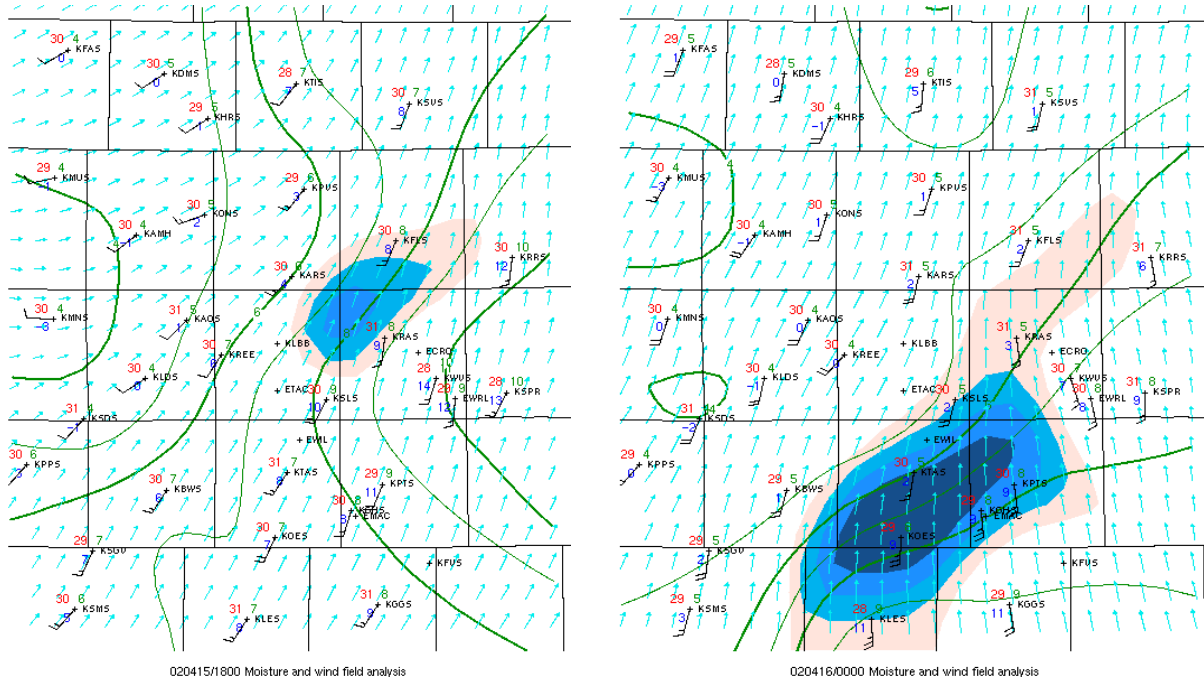
Evaluating  $(S2 - S1)$  at 12 hours, notable differences are seen in the proximity of the WTM (Figures 8a and 8b). However, all differences vanished within 3 hours after the end of FDDA.



**Figures 8a (left) and 8b (right).  $(S2-S1)$  at 12h for V (Fig. 8a, left) and T (Fig. 8a, right).**

### 3.2 Case study of 15- 16 April 2002

This represents a case of relatively tranquil (no convection or precipitation) moist springtime conditions over the domain. During April 15- 16, a quiescent dryline (the dryline is a “moisture front” where high-dewpoint Gulf of Mexico air meets dry desert air, a regular warm-season mesoscale feature of the southern Great Plains) crossed the West Texas Mesonet domain. A nested double grid ( $\Delta = 6$  km and 18 km, respectively) 24-hour MM5 simulation was performed, initialized at 00 UTC 15 April 2002. A surface analysis of the dryline position after 18 hours (Figure 9a) and 24 hours (Figure 9b) is shown below. The green lines represent mixing ratio (g/kg). Areas of moisture convergence are shaded on the figure. The dryline was located to the east of Lubbock, and it shifted southeastward in six hours.



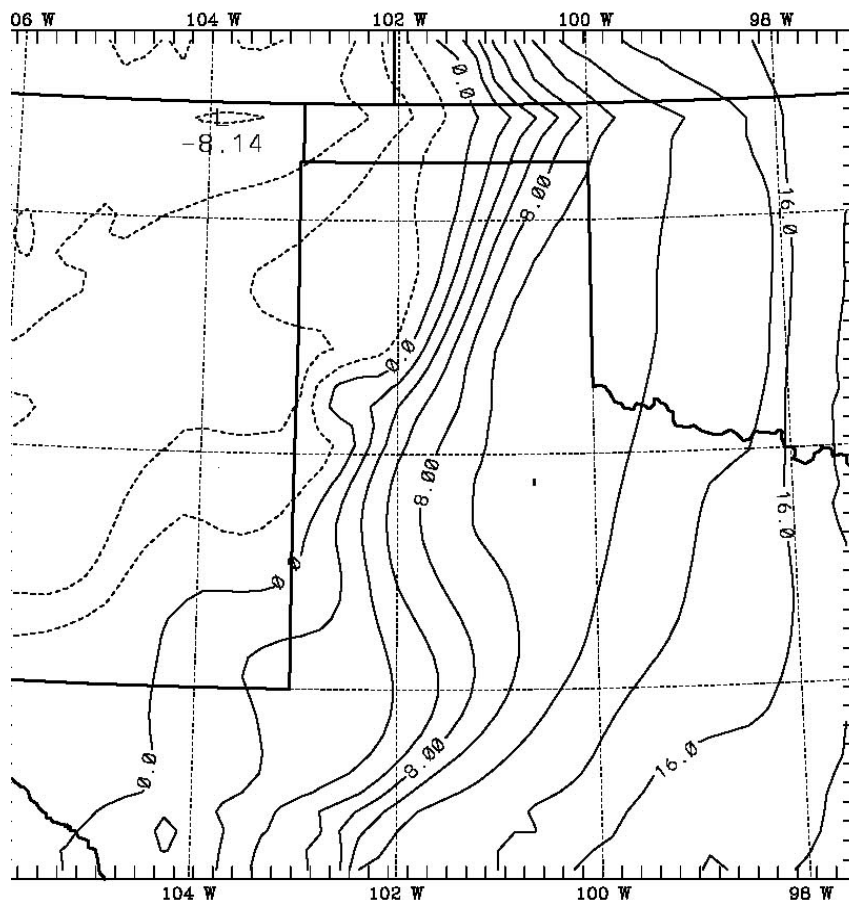
**Figure 9a (left) and 9b (right). Surface analysis of actual dryline position using WTM data for 18 UTC 15 April (Fig. 9a, left) and at 00 UTC 16 April (Fig. 9b, right). Areas of moisture convergence are shaded, and green lines represent mixing ratio (g/kg).**

The model dryline was located slightly to the west of the observed position at 18 UTC 15 April (Figure 10) and showed little movement with time. Repeating the FDDA as per the parameters of the November 2002 case described in section 3.1 also produced little or no real improvement.

### 3.3 Overview of MM5 case studies and FDDA

MM5 generally performed fairly well against West Texas Mesonet data in all the case studies. However, 6-hour, 9-hour, and 12-hour four-dimensional data assimilations based on the 10-meter West Texas Mesonet tower data showed little impact on surface wind, moisture and precipitation forecasting. The model did not retain small-scale features embedded in the data three hours after the four-dimensional data assimilations were terminated.





**Figure 10. MM5 coarse-grid simulated dewpoint temperature at 18 UTC 15 April 2002.**

#### **4. HPAC diffusion computations**

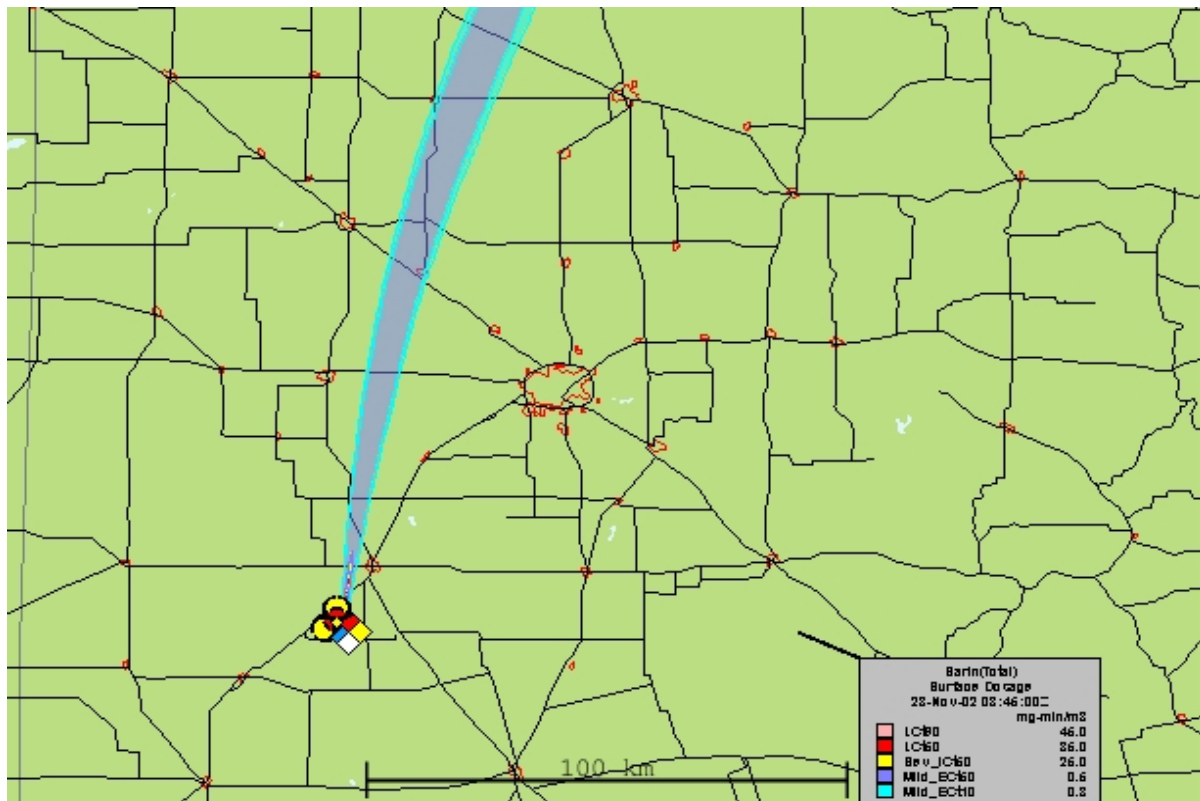
MM5 model outputs were used as the required meteorological inputs to HPAC (Hazard Prediction and Assessment Capability) diffusion computations. The incident chosen was a hypothetical chemical-biological agent release near the ground surface at a location of industrial facilities southeast of Lubbock. The domain of interest was the West Texas Mesonet. HPAC surface dosage was used for footprint plots to assess and display potential hazards and collateral effects of agent release. The HPAC-provided terrain was used in all HPAC runs.

The MM5 case 1 evaluated in section 3.1 above (23- 24 Nov. 2002) is used as an illustrative example, representing quiescent conditions and a tranquil synoptic setting. Such quiescent conditions would generally represent the largest risk to populations during an actual chemical/biological incident. Being able to model conditions in periods of quiescent weather will be a necessary first test of model performance. Outcomes of these type of cases will be useful in defining a baseline for interpretations of more dynamic cases.

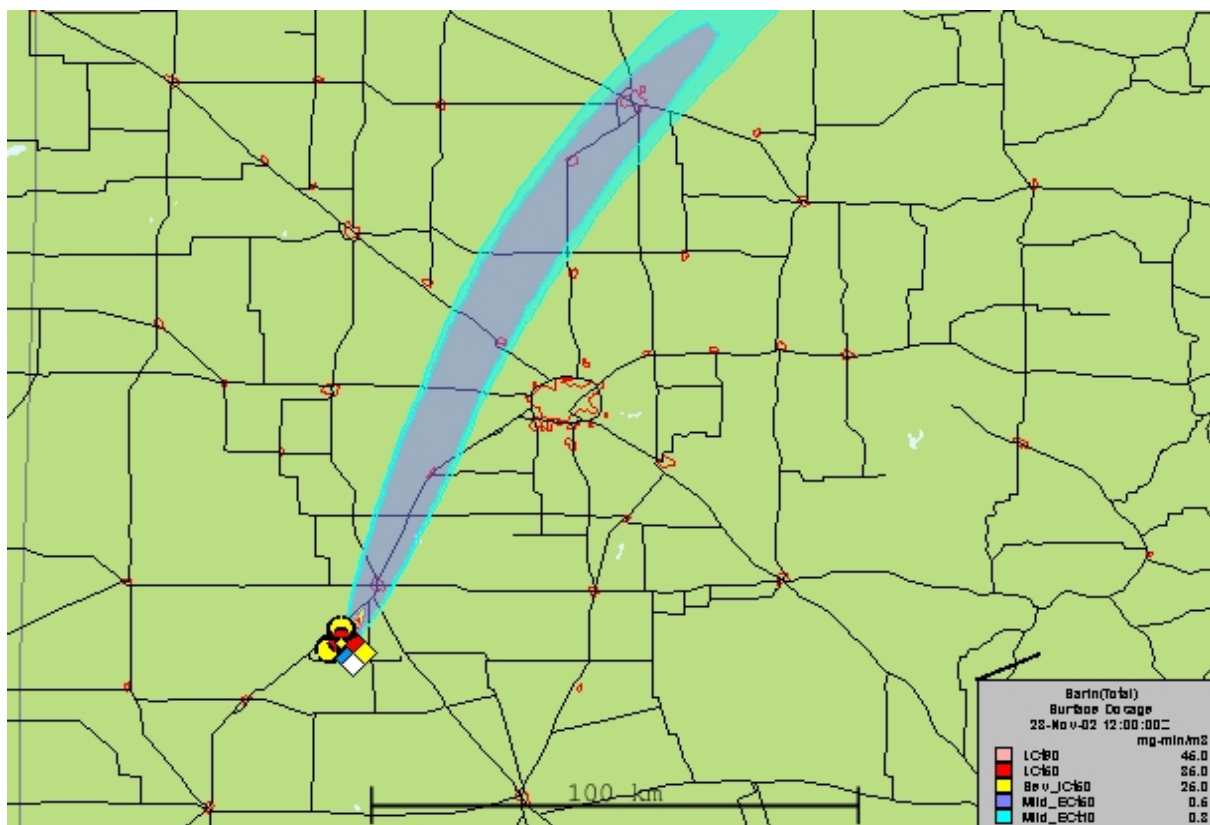
In this example, MM5 was run in a single grid with 67 by 67 horizontal grid points with  $\Delta = 15$  km, centered on the West Texas Mesonet. Twenty-two vertical levels were utilized for input to HPAC. As above, real-data FDDA experiments by observational nudging of the West Texas Mesonet data into the model were also performed. Initial state and lateral boundary conditions were derived from the NCEP ETA products. Input data were the hourly 10-m wind, temperature, and humidity. A forecast time period starting in late afternoon local time was chosen to

maximize the impact of FDDA during the night when the convective boundary layer dissipated. The FDDA results were the same as discussed in Section 3.1 above: discrepancies occurred over the West Texas Mesonet, but dissipated rapidly after FDDA was turned off.

For HPAC, the computation domain was the region of 31°- 36° North latitude by 99° - 104° West longitude. The chosen incident type was chemical and biological facilities, with a release of GB at 00 UTC, 23 November. The release location was 33.2° North latitude by 102° West longitude (about 70 km SW of Lubbock). The HPAC run based on the Mesonet data (Figure 11a) was taken as a benchmark for evaluating the diffusion computations using the MM5 simulated data. The diffusion computed with the MM5 simulated vertical profile data (Figure 11b) is wider than the one with Mesonet data, but they are in reasonably good agreement in path. An HPAC run using the grid mode of MM5 data (not shown) produced an unrealistic veering plume. The use of FDDA simulated winds (also not shown) resulted in very little change in the plume location.



**Figure 11a.** HPAC computed surface dosage at 12 UTC 23 November 2002 using the hourly West Texas Mesonet data.



**Figure 11b. HPAC computed surface dosage at 12 UTC 23 November 2002 using the three-hourly MM5 simulated profile data.**

## 5. Conclusions and Suggestions

We have shown that observational networks such as the West Texas Mesonet are useful for studies investigating the performance of numerical meteorological models such as MM5 and HPAC. In our case studies, MM5 performed essentially the same in reproducing the observed surface flows with and without four-dimensional data assimilation using the Mesonet data.

The sensitivity of HPAC diffusion computations (Gill *et al.*, 2003) may be a strong function of environmental conditions, and the forecast skill of mesoscale models is likely to be a function of weather scenarios. Because numerical techniques are different and the model physics (e.g., BL, surface, and moist processes) vary considerably between models, we anticipate there may be some discrepancies between individual model predictions. A state-of-the-art mesoscale model therefore might perform well in some scenarios but not in others. There could be a potential benefit of using several model winds separately to run HPAC: a composite result of the HPAC runs might then give a more comprehensive depiction of the transport of hazardous agents at the surface.

## 6. Acknowledgements

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